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(54) **ACOUSTIC WAVE DEVICE, FILTER AND MULTIPLEXER**

(71) Applicant: **TAIYO YUDEN CO., LTD.**, Tokyo (JP)

(72) Inventors: **Kazushige HATAKEYAMA**, Tokyo (JP); **Jyunichi HAMASAKI**, Tokyo (JP)

(73) Assignee: **TAIYO YUDEN CO., LTD.**, Tokyo (JP)

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(57) **ABSTRACT**

An acoustic wave device includes a first substrate, an acoustic wave element provided on a first surface of the piezoelectric layer, a second substrate, a first metal layer provided on the first surface and conductively connected to the acoustic wave element, a second metal layer provided on a second surface of the second substrate, a third metal layer that connects the first metal layer to the second metal layer, is thicker than the first metal layer and the second metal layer, and contains copper or silver, and a first conductive layer that covers a side surface of the third metal layer, and a third surface of the first metal layer in a region surrounding another region where the third metal layer is bonded to the first metal layer, is thinner than the third metal layer, and contains a component other than copper, silver, and tin as a main component.

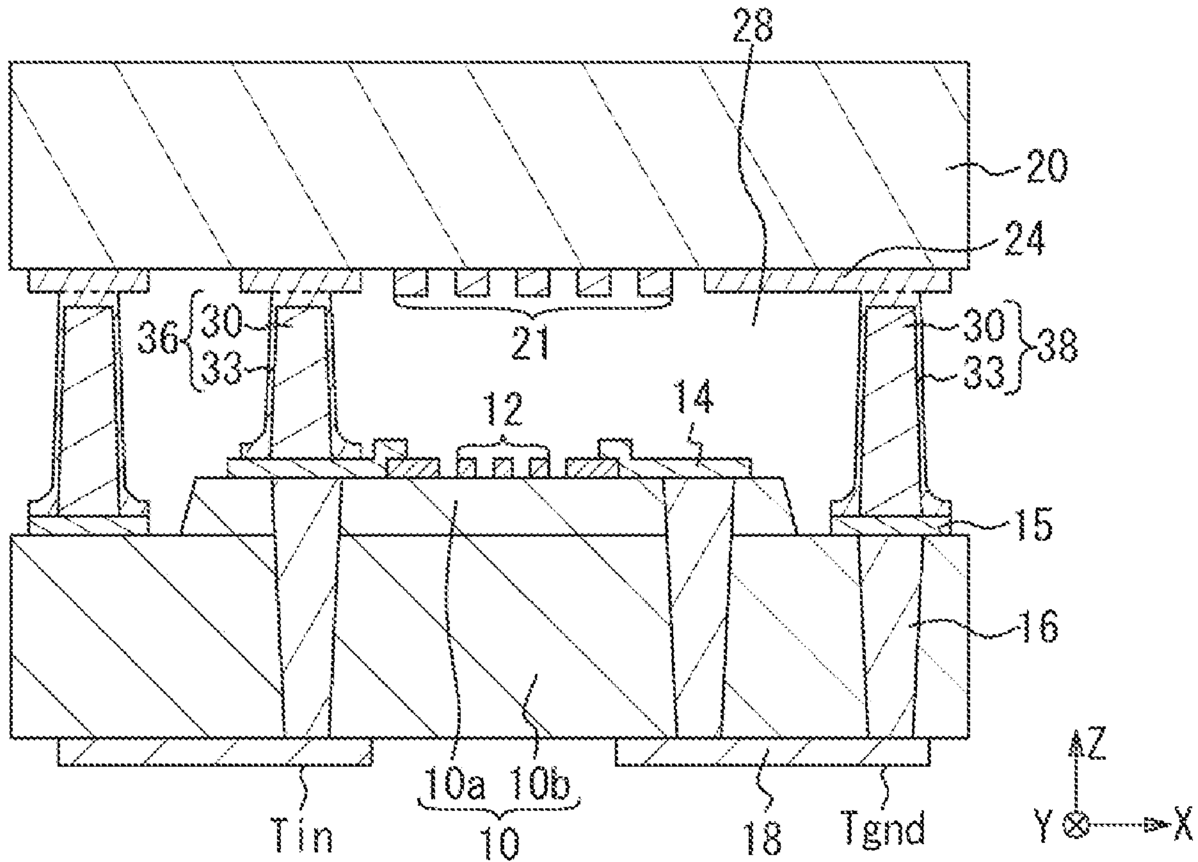


FIG. 1A

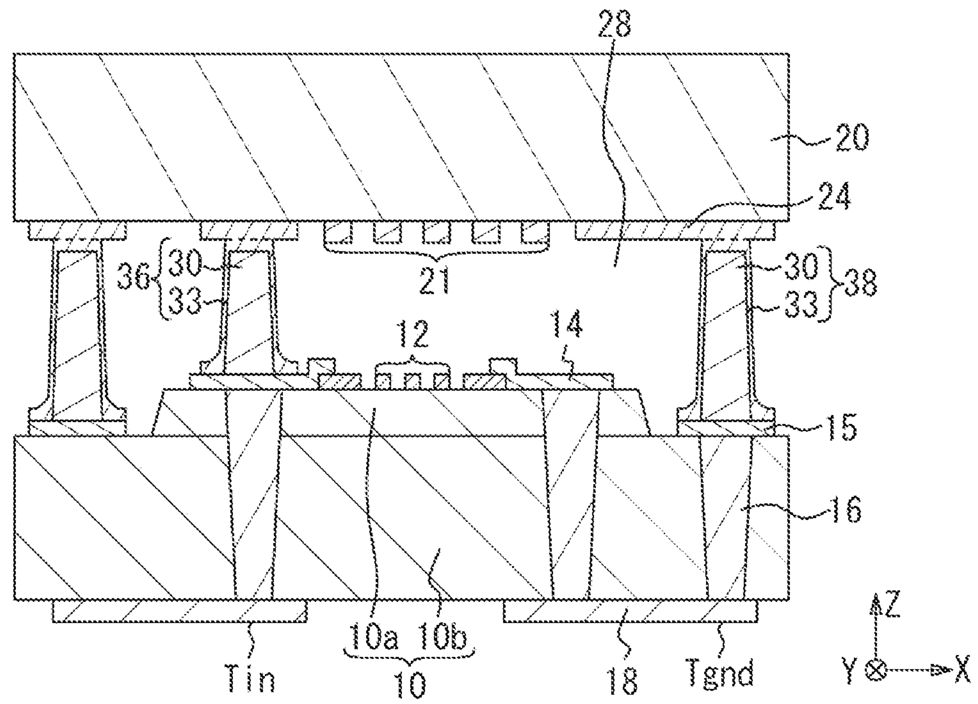


FIG. 1B

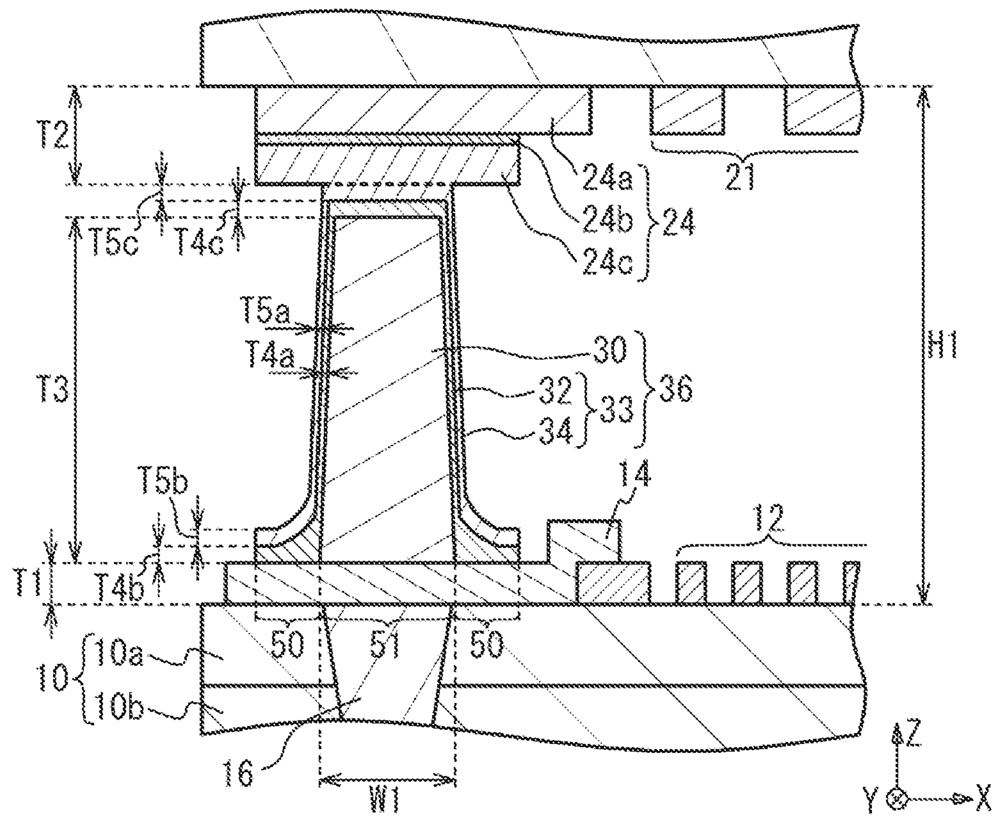


FIG. 2

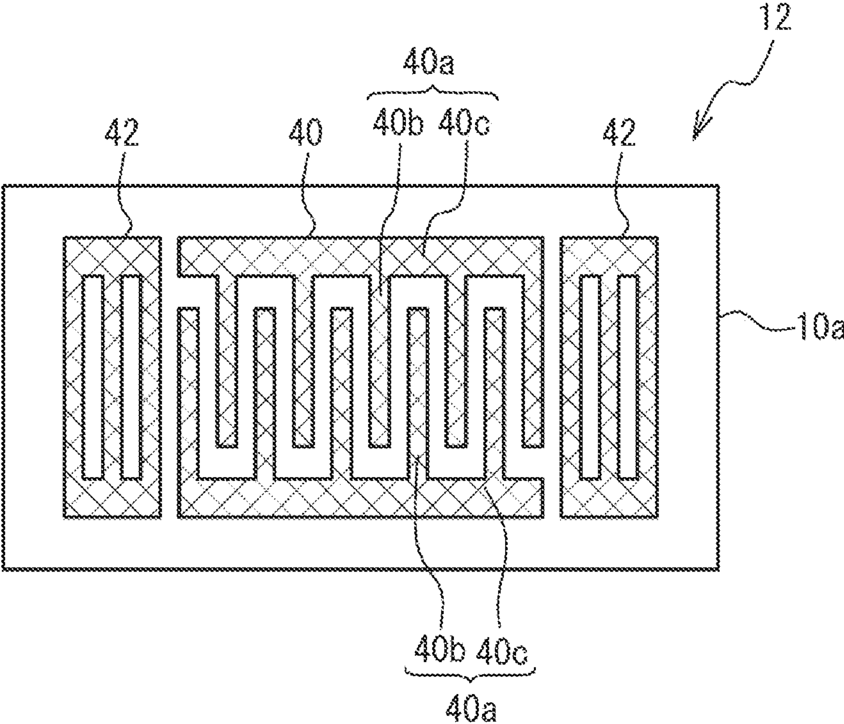


FIG. 3A

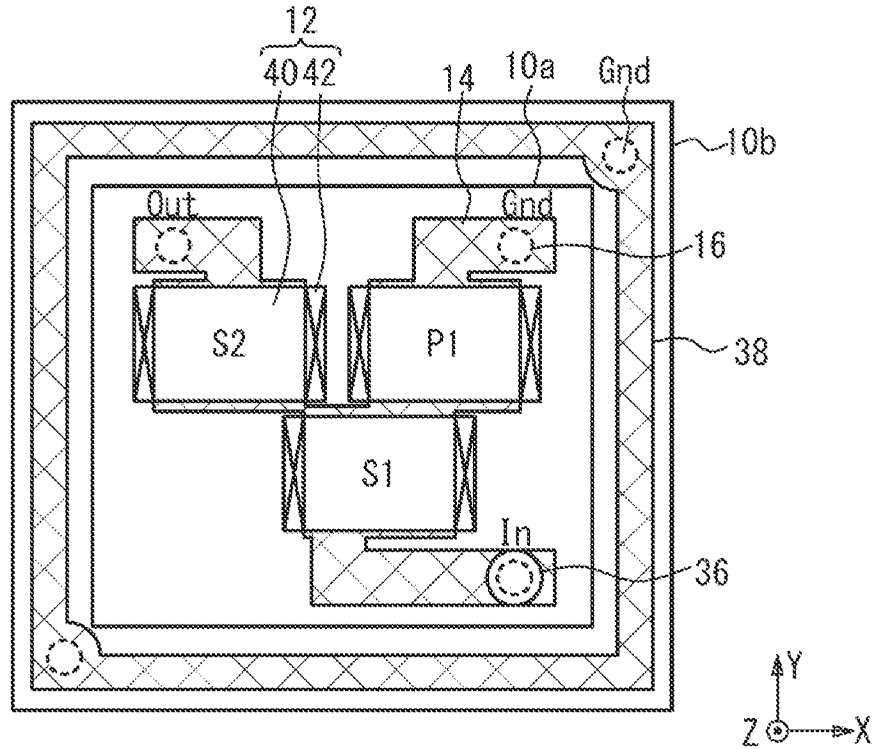


FIG. 3B

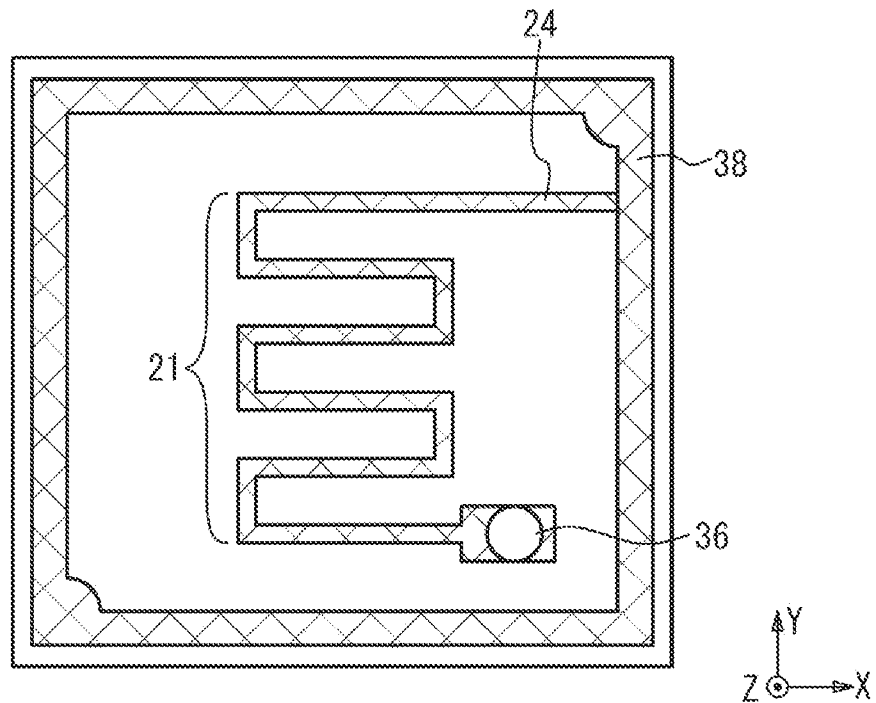


FIG. 4A

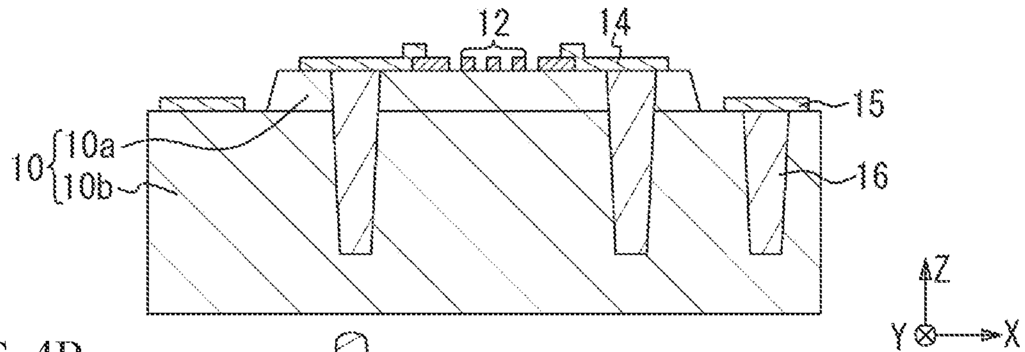


FIG. 4B

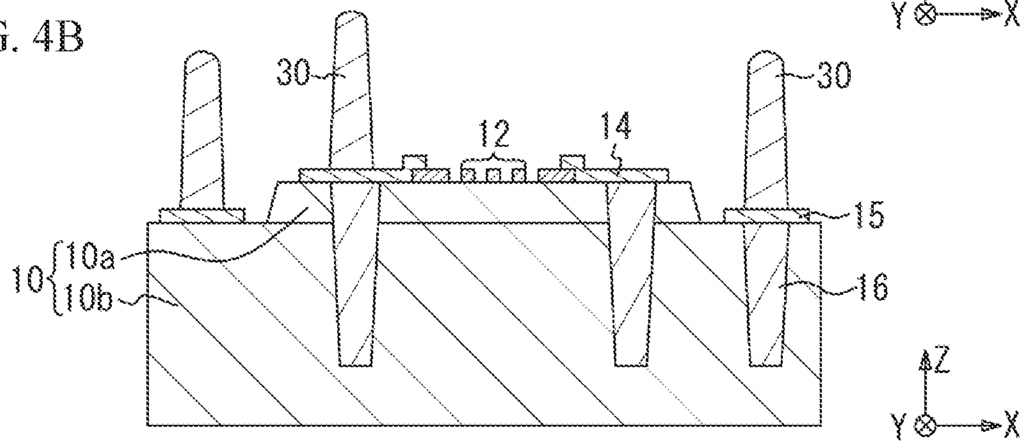


FIG. 4C

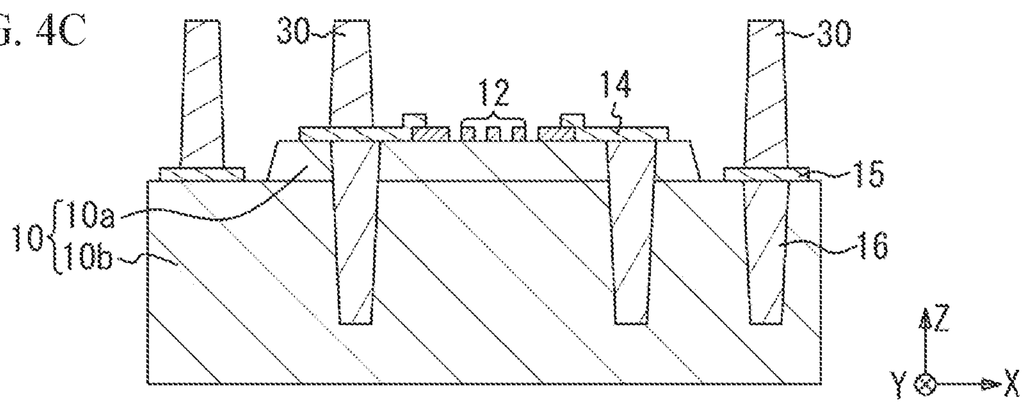
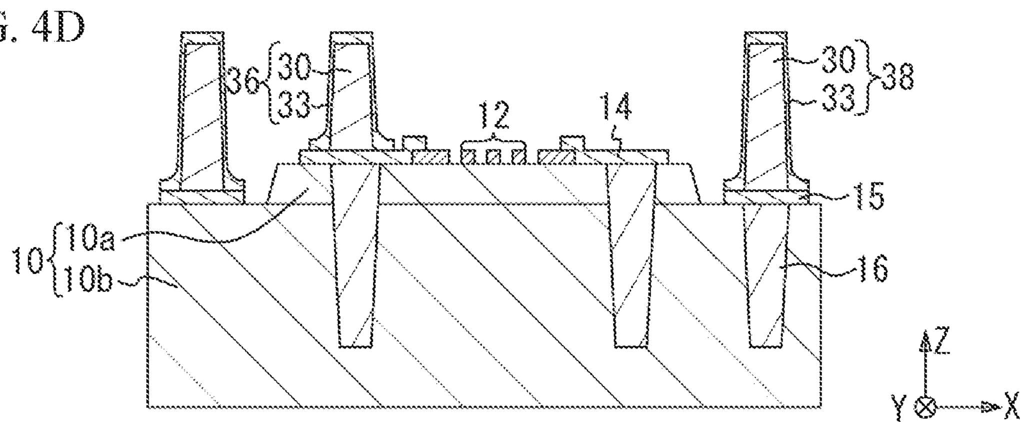


FIG. 4D



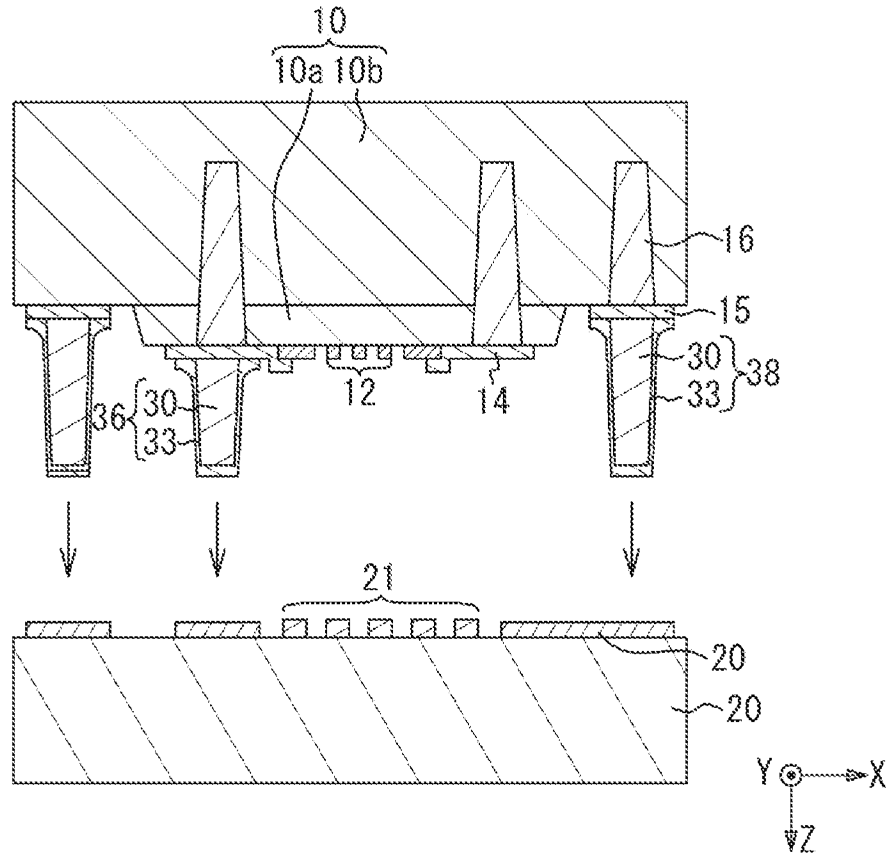


FIG. 5A
10
10a 10b
16
15
30
38
33
36
30
33
12
14
21
20
20
Y
X
Z

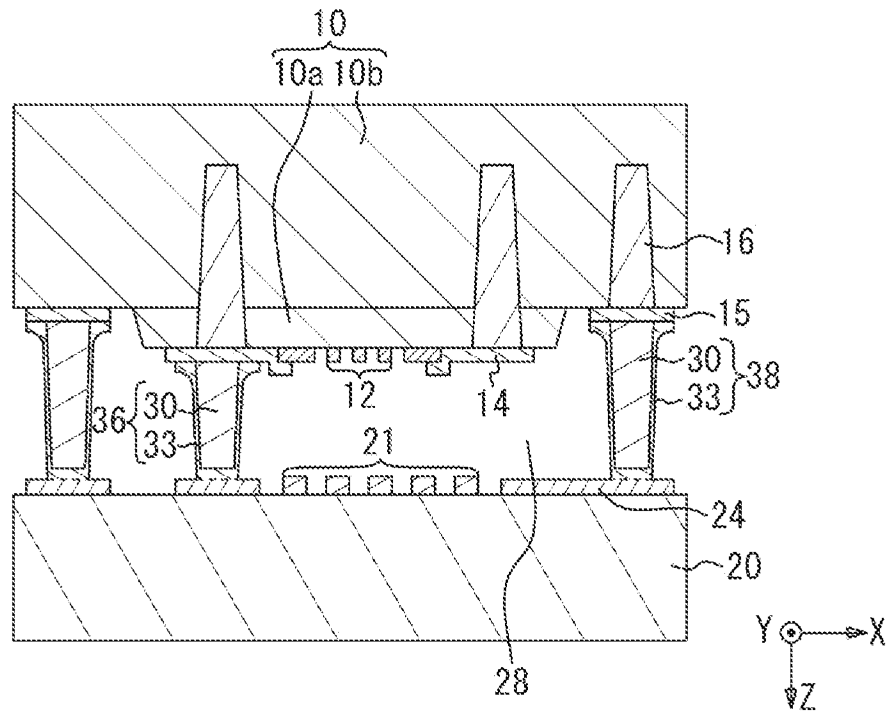


FIG. 5B
10
10a 10b
16
15
30
38
33
36
30
33
12
14
21
24
20
28
Y
X
Z

FIG. 6

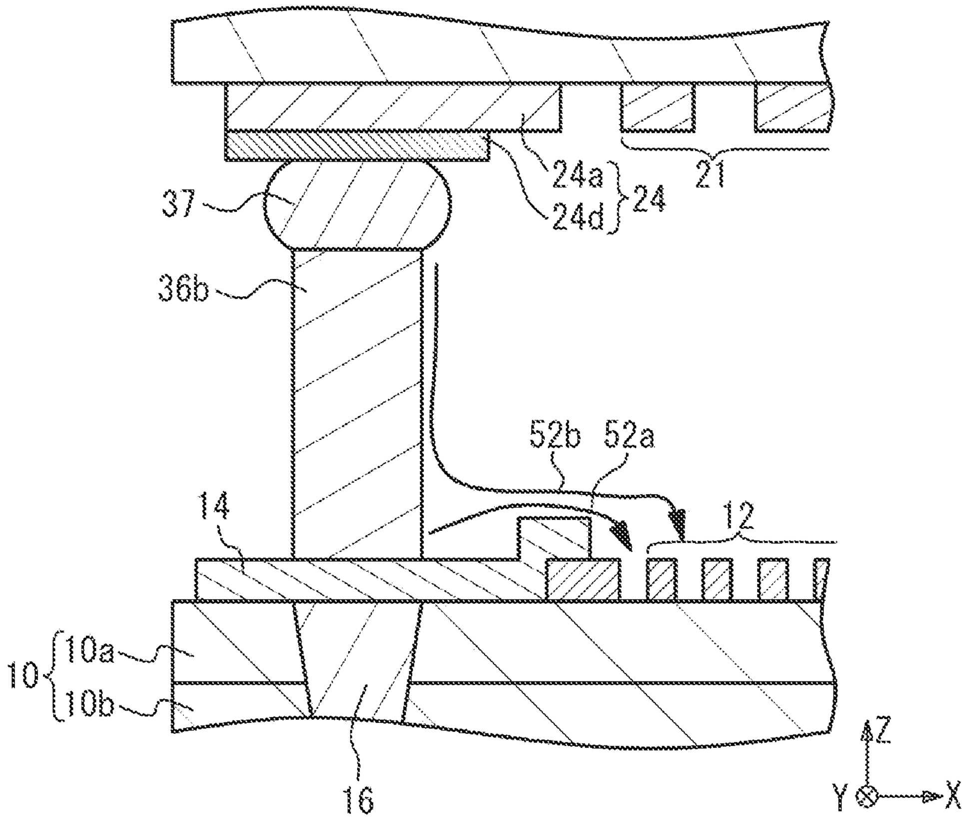


FIG. 7A

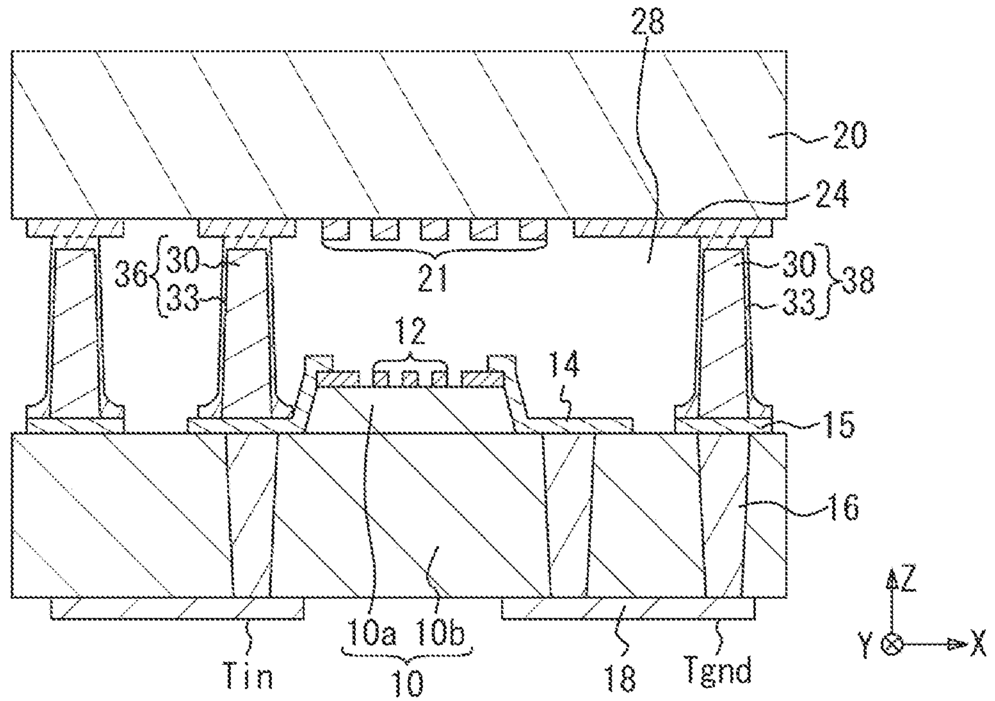


FIG. 7B

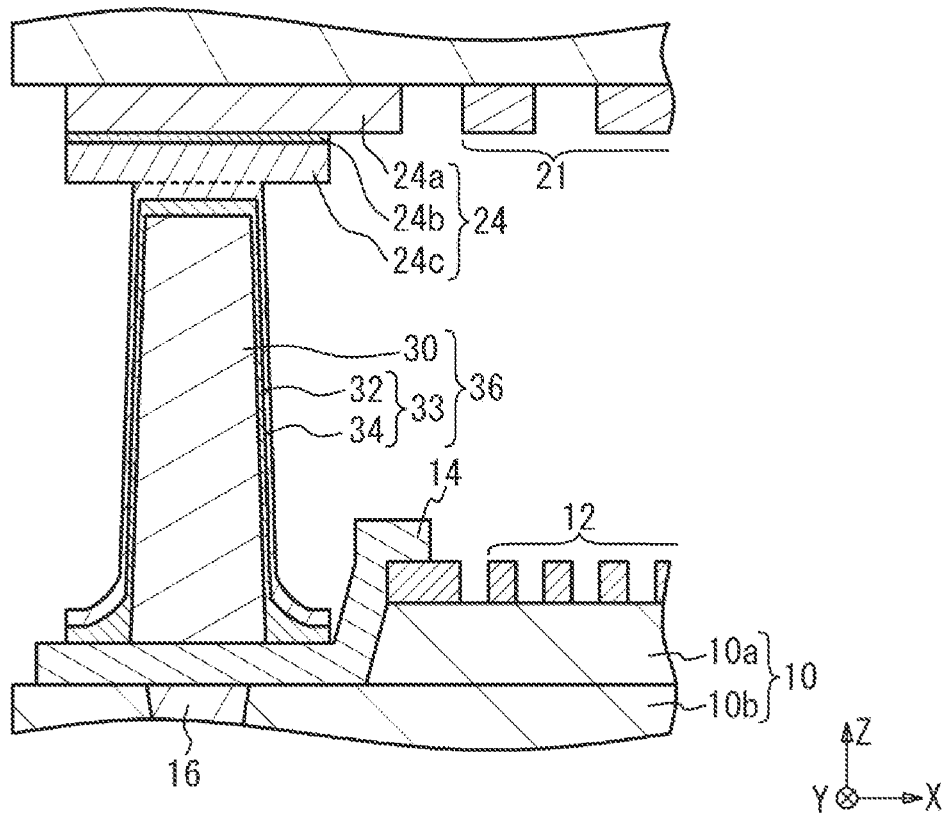


FIG. 8A

FIG. 8B

FIG. 9

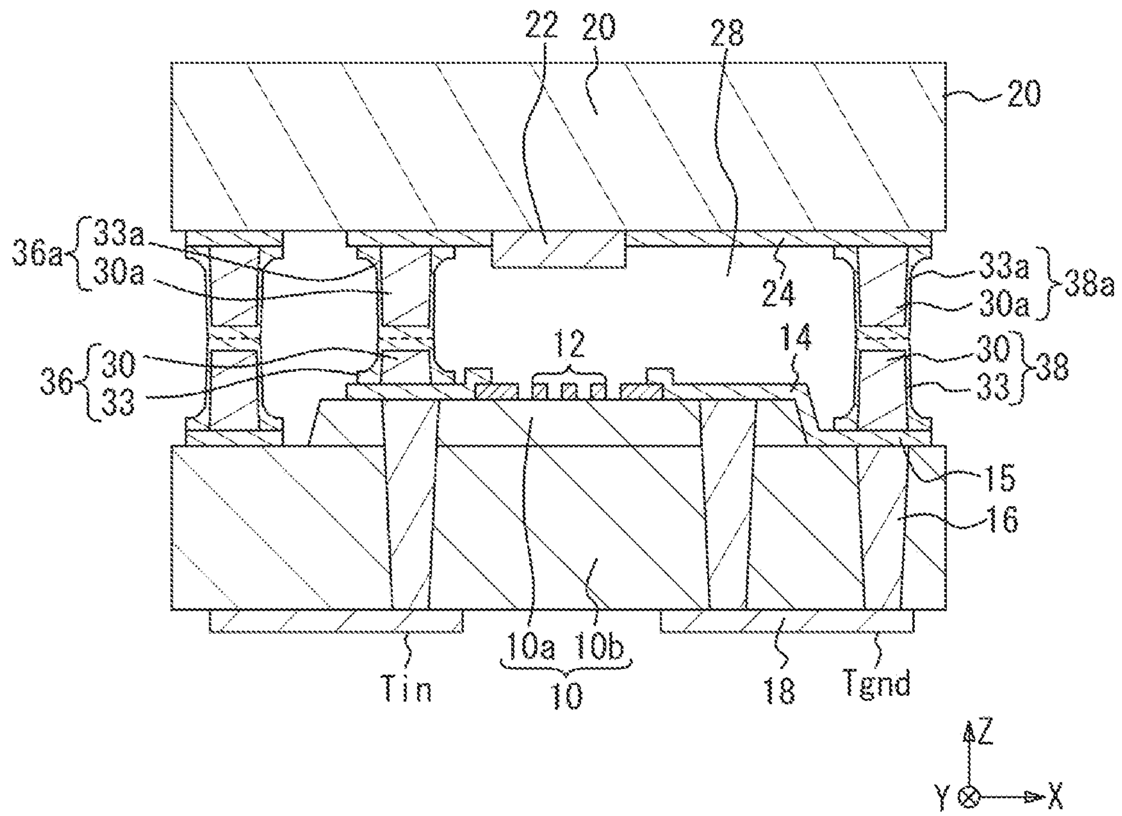


FIG. 10

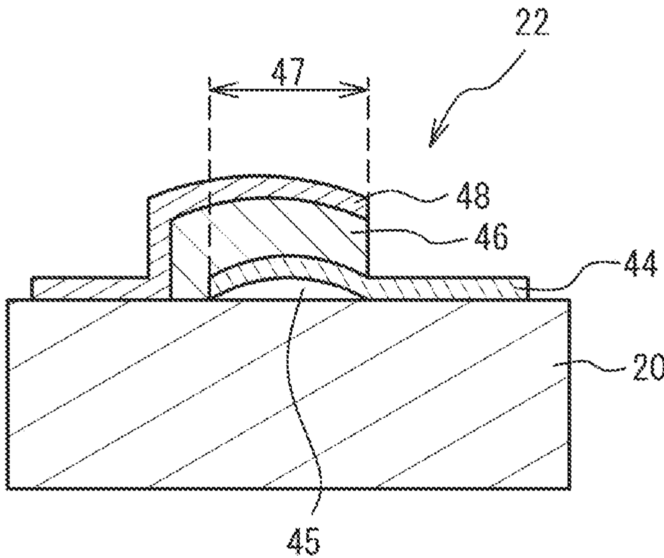


FIG. 11

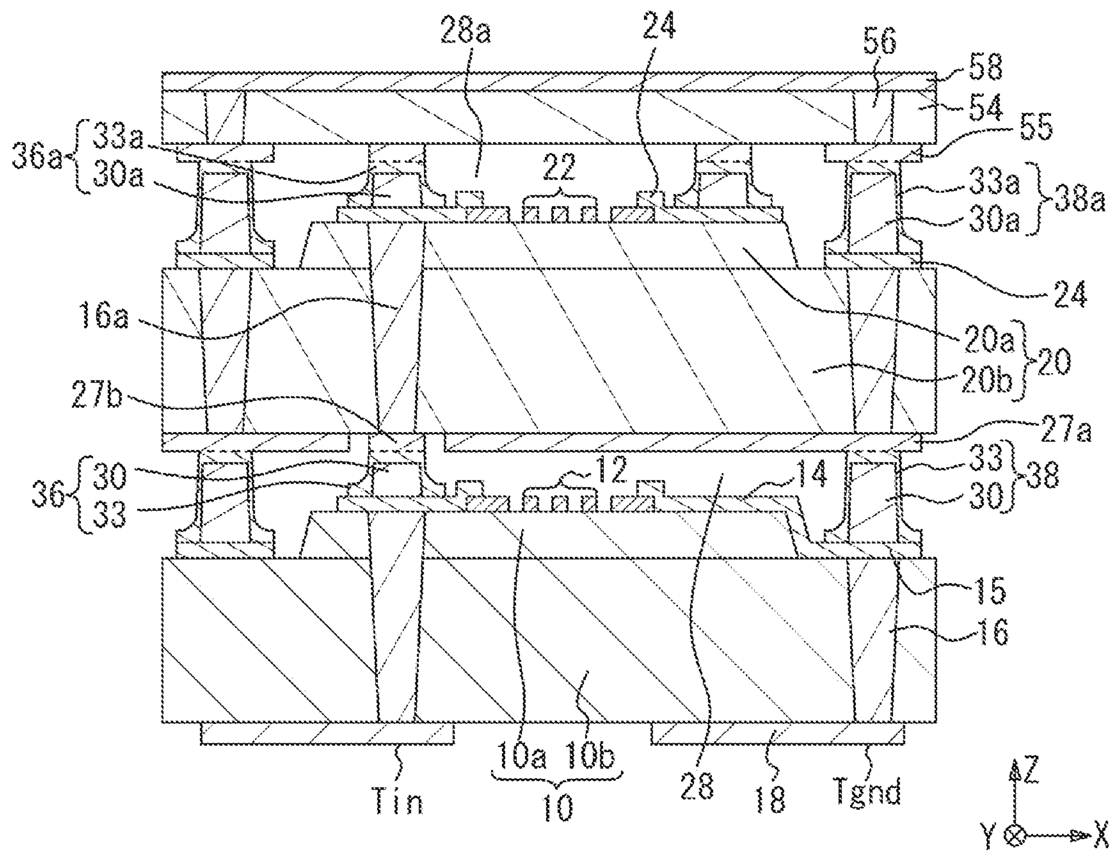


FIG. 12A

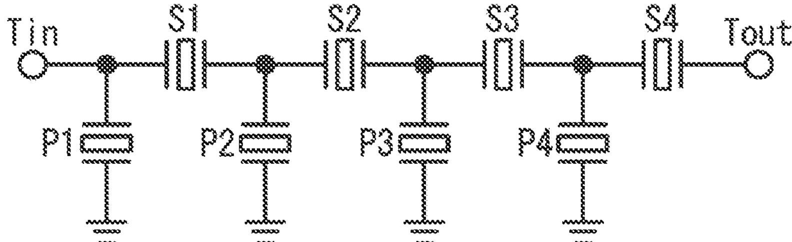
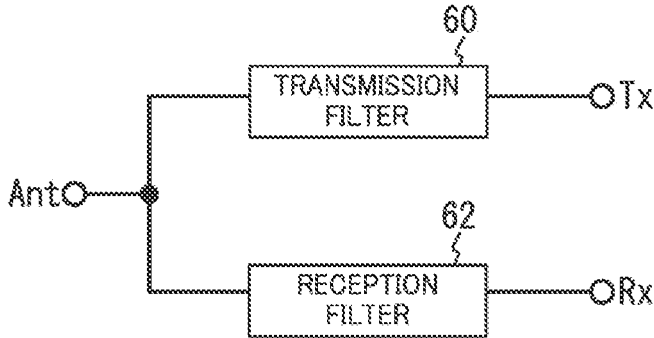


FIG. 12B



ACOUSTIC WAVE DEVICE, FILTER AND MULTIPLEXER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2021-106573, filed on Jun. 28, 2021, the entire contents of which are incorporated herein by reference.

FIELD

[0002] A certain aspect of the present invention relates to an acoustic wave device, a filter and a multiplexer.

BACKGROUND

[0003] There has been known an acoustic wave device in which an acoustic wave element is provided on a substrate, another substrate such as a lid is arranged on the acoustic wave element, and the substrate and the another substrate are connected by using a metal layer (for example, see Japanese Patent Application Publications No. 2004-364041, No. 2007-89143 and No. 2015-146523, and Japanese National Publication of International Patent Application No. 2010-526456). In an underbump metal layer, it has been known that another metal layer is provided so as to cover a side surface and an upper surface of a metal layer (for example, see Japanese Patent Application Publications No. 10-13184 and No. 2002-100951).

SUMMARY OF THE INVENTION

[0004] A piezoelectric substrate is easily charged, and if the metal layer connecting the substrate to the another substrate contains copper or silver as a main component, copper or silver ions may migrate to the acoustic wave element.

[0005] The present disclosure has been made in view of the above problem, and an object of the present disclosure is to suppress ion migration of copper or silver.

[0006] According to an aspect of the present invention, there is provided an acoustic wave device including: a first substrate having at least a part of a first surface that is a piezoelectric layer; an acoustic wave element provided on the first surface of the piezoelectric layer; a second substrate provided apart from the first substrate via the acoustic wave element and a gap; a first metal layer provided on the first surface and conductively connected to the acoustic wave element; a second metal layer provided on a second surface of the second substrate on a first substrate side; a third metal layer that connects the first metal layer to the second metal layer, is thicker than the first metal layer and the second metal layer, and contains copper or silver as a main component; and a first conductive layer that covers a side surface of the third metal layer, and a third surface of the first metal layer on a second substrate side in a region surrounding another region where the third metal layer is bonded to the first metal layer, is thinner than the third metal layer, and contains a component other than copper, silver, and tin as a main component.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1**A is a cross-sectional view illustrating an acoustic wave device according to a first embodiment;

[0008] FIG. **1**B is an enlarged view illustrating the vicinity of a metal pillar in FIG. **1**A;

[0009] FIG. **2** is a plan view illustrating the acoustic wave element according to the first embodiment;

[0010] FIGS. **3**A and **3**B are plan views illustrating the acoustic wave device according to the first embodiment;

[0011] FIGS. **4**A to **4**D are cross-sectional views illustrating a method of manufacturing the acoustic wave device according to the first embodiment (No. 1);

[0012] FIGS. **5**A and **5**B are cross-sectional views illustrating a method of manufacturing the acoustic wave device according to the first embodiment (No. 2);

[0013] FIG. **6** is an enlarged view illustrating the vicinity of a metal pillar in a first comparative example;

[0014] FIG. **7**A is a cross-sectional view illustrating an acoustic wave device according to a first modification of the first embodiment;

[0015] FIG. **7**B is an enlarged view illustrating the vicinity of a metal pillar in FIG. **7**A;

[0016] FIGS. **8**A and **8**B are cross-sectional views illustrating an acoustic wave device according to second and third modifications of the first embodiment, respectively;

[0017] FIG. **9** is a cross-sectional view illustrating an acoustic wave device according to a fourth modification of the first embodiment;

[0018] FIG. **10** is a cross-sectional view illustrating an acoustic wave element according to the fourth modification of the first embodiment;

[0019] FIG. **11** is a cross-sectional view illustrating an acoustic wave device according to a fifth modification of the first embodiment;

[0020] FIG. **12**A is a circuit diagram illustrating a filter according to a second embodiment; and

[0021] FIG. **12**B is a circuit diagram illustrating a duplexer according to a first modification of the second embodiment.

DETAILED DESCRIPTION

[0022] A description will be given of an embodiment with reference to the accompanying drawings.

First Embodiment

[0023] FIG. **1**A is a cross-sectional view illustrating an acoustic wave device according to a first embodiment, and FIG. **1**B is an enlarged view illustrating the vicinity of a metal pillar in FIG. **1**A. A thickness direction of a substrate **10** is a Z direction, and plane directions of the substrate **10** are an X direction and a Y direction.

[0024] As illustrated in FIG. **1**A, the substrate **10** includes a support substrate **10*b*** and a piezoelectric substrate **10*a*** provided on the support substrate lob. One layer or a plurality of insulating films such as a silicon oxide film and an aluminum oxide film may be provided between the support substrate **10*b*** and the piezoelectric substrate **10*a***. An acoustic wave element **12** and a metal layer **14** are provided on the piezoelectric substrate **10*a***. The acoustic wave element **12** is, for example, a surface acoustic wave element. The metal layer **14** functions as a wiring and a pad electrically connected to the acoustic wave element **12**. The piezoelectric substrate **10*a*** on a peripheral edge of the substrate **10** is removed, and a metal layer **15** is provided on the support substrate **10*b*** on the peripheral edge of the substrate **10** so as to surround the acoustic wave element **12**.

Via wirings **16** penetrating the substrate **10** are provided. Terminals **18** are provided on a lower surface of the substrate **10**. The terminals **18** function as an input terminal Tin, an output terminal (not illustrated), and a ground terminal Tgnd. The via wiring **16** electrically connects the metal layer **14** to the terminal **18**. A substrate **20** is provided above the substrate **10**. A metal pillar **36** is provided on the metal layer **14**. An annular metal layer **38** is provided on the metal layer **15** so as to surround the acoustic wave element **12**.

[0025] The piezoelectric substrate **10***a* is, for example, a piezoelectric substrate such as a single crystal lithium tantalate substrate, a single crystal lithium niobate substrate, or a single crystal quartz substrate. The single crystal lithium tantalate substrate and the single crystal lithium niobate substrate are, for example, rotary Y-cut X propagation substrates. The support substrate **10***b* is, for example, a sapphire substrate, an alumina substrate, a quartz substrate, a crystal substrate, a spinel substrate, a SiC substrate, or a silicon substrate. Each of the metal layer **14**, the metal layer **15**, the via wiring **16** and the terminal **18** is a single layer made of a metal layer such as a copper layer, a gold layer, a silver layer, a titanium layer, a nickel layer, and a tungsten layer, or laminated layers made of these layers.

[0026] The substrate **20** is provided above the substrate **10** via a space **28**. Elements **21** and a metal layer **24** are provided on a lower surface of the substrate **20**. Each element **21** is a passive element such as an inductor or a capacitor. The metal pillar **36** connects the metal layer **14** to the metal layer **24**. The annular metal layer **38** connects the metal layer **15** to the metal layer **24**. The acoustic wave element **12** and the elements **21** are sealed in the space **28** by the annular metal layer **38** and the substrates **10** and **20**. Each of the metal pillar **36** and the annular metal layer **38** includes a metal layer **30** and a metal layer **33** that covers the metal layer **30**. The substrate **20** is, for example, a sapphire substrate, an alumina substrate, a quartz substrate, a quartz crystal substrate, a spinel substrate, a SiC substrate, or a silicon substrate. The metal layer **24** is, for example, a single layer made of a metal layer such as a copper layer, a gold layer, a silver layer, a titanium layer, a nickel layer, and a tungsten layer, or laminated layers made of these layers.

[0027] As illustrated in FIG. **1**B, the metal layer **33** covers a region **50** of a surface of the metal layer **14**, an upper surface and a side surface of the metal layer **30**. The region **50** is a region surrounding a bonding region **51** in which the metal layer **30** is bonded to the metal layer **14**. The metal layer **33** may be provided in at least a region in the region **50** between the metal layer **30** and the acoustic wave element **12**. The metal layer **33** includes the metal layer **32** that contacts the region **50** and the upper surface and the side surface of the metal layer **30**, and the metal layer **34** that covers the metal layer **32** and contacts the metal layer **32**. The metal layer **30** contains copper or silver as a main component. The metal layer **34** contains, for example, gold or aluminum as a main component. The metal layer **32** is a barrier layer that suppresses the migration of copper or silver, and contains, for example, at least one element of titanium, chromium, tantalum, nickel, tungsten, and ruthenium, or a nitride of the at least one element as a main component.

[0028] The metal layer **24** includes metal layers **24***a* to **24***c*. The metal layer **24***a* is electrically connected to the element **21**. The metal layer **24***c* is directly bonded to the metal layer **34**. The metal layer **24***b* is provided between the metal layers **24***a* and **24***c*. Since the metal layer **24***c* is directly bonded to the metal layer **34**, for example, the main components of the metal layers **24***c* and **34** are the same as each other. The metal layer **24***c* contains, for example, gold or aluminum as a main component. The metal layer **24***b* is a diffusion-preventing barrier layer between the metal layers **24***a* and **24***c*, and contains, for example, at least one element of titanium, chromium, tantalum, nickel, tungsten and ruthenium, or a nitride of the at least one element as a main component.

[0029] The thicknesses of the metal layers **14**, **24** and **30** are T**1** to T**3**, respectively. The thicknesses of the metal layer **32** covering the upper surface and the side surface of the metal layer **30** are T**4***c* and T**4***a*, respectively, and the thicknesses of the metal layer **34** covering the upper surface and the side surface of the metal layer **32** are T**5***c* and T**5***a*, respectively. The thickness of the metal layer **32** covering the region **50** is T**4***b*. The thickness of the metal layer **34** covering the region **50** is T**5***b*.

[0030] The thicknesses T**1** and T**2** of the metal layers **14** and **24** are, for example, 0.1 μm to 5 μm. The thickness T**3** of the metal layer **30** is, for example, 10 μm to 100 μm. Since the metal layers **14** and **24** function as wirings extending in the plane direction, the thicknesses T**1** and T**2** are relatively thin. The metal layer **30** has a relatively thick thickness T**3** because the metal layer **30** connects the substrate **10** to the substrate **20** and the width of the space **28** in the Z direction is increased. The thickness T**3** is, for example, twice or more, or five times or more the thickness T**1**+T**2**. The thickness T**3** of the metal layer **30** is, for example, ½ or more or ⅘ or more of a height H**1** in the Z direction between the substrates **10** and **20**. A width W**1** of the metal layer **30** is, for example, 20 μm to 200 μm. As the width W**1** increases, an area of the chip plane increases. Therefore, an aspect ratio T**3**/W**1** is 0.4 or more, preferably 0.6 or more, and more preferably 1.0 or more. Each of the thicknesses T**4***a* to T**4***c* and T**5***a* to T**5***c* is 20 nm to 200 nm. The thickness T**4***b* is smaller than the thicknesses T**4***a* and T**4***c*, and the thickness T**5***b* is smaller than the thicknesses T**5***a* and T**5***c*. For example, "T**4***a*:T**4***b*=T**5***a*:T**5***b*=2:5" is satisfied. Since the metal layer **33** covers the side surface of the metal layer **30**, a cross-sectional shape of the metal layer **30** is, for example, trapezoidal, and a taper angle of the side surface is, for example, 70° or more and less than 90°.

[0031] FIG. **2** is a plan view illustrating the acoustic wave element according to the first embodiment. As illustrated in FIG. **2**, the acoustic wave element **12** is a surface acoustic wave resonator or a Lamb wave resonator. An IDT (Interdigital Transducer) **40** and reflectors **42** are formed on the piezoelectric substrate **10***a*. The IDT **40** has a pair of interdigital electrodes **40***a* facing each other. The interdigital electrode **40***a* has a plurality of electrode fingers **40***b* and a bus bar **40***c* that connects the plurality of electrode fingers **40***b*. The reflectors **42** are provided on both sides of the IDT **40**. The IDT **40** excites a surface acoustic wave on the substrate **10** which is a piezoelectric substrate. The wavelength of the acoustic wave is substantially equal to a pitch between the electrode fingers **40***b* in one of the pair of interdigital electrodes **40***a*. That is, the wavelength of the acoustic wave is substantially equal to twice a pitch between the electrode fingers **40***b* in the pair of interdigital electrodes **40***a*. The IDT **40** and the reflectors **42** are formed of, for example, an aluminum film, a copper film or a molybdenum film. A protective film or a temperature compensation film

may be provided on the piezoelectric substrate **10***a* so as to cover the IDT **40** and the reflectors **42**. The acoustic wave element **12** includes an electrode that excites the acoustic wave. Therefore, the acoustic wave element **12** is covered with the space **28** so as not to limit the acoustic wave.

[0032] FIGS. **3**A and **3**B are plan views illustrating the acoustic wave device according to the first embodiment. FIG. **3**A is a plan view illustrating an upper surface of the substrate **10**, and FIG. **3**B is a plan view illustrating the lower surface of the substrate **10** transmitted from above. As illustrated in FIG. **3**A, the piezoelectric substrate **10***a* on the peripheral edge of the substrate **10** is removed, and the annular metal layer **38** is provided on the peripheral edge of the substrate **10**. The annular metal layer **38** is connected to the ground terminal provided on the lower surface of the substrate **10** via the via wiring **16**. The acoustic wave element **12** and the metal layer **14** are provided on the piezoelectric substrate **10***a*. The acoustic wave element **12** is an acoustic wave resonator and includes the IDT **40** and the reflectors **42**. The metal layer **14** functions as a pad to which the wiring for connecting the acoustic wave element **12** and the via wiring **16** are connected. The acoustic wave element **12** includes series resonators S**1** and S**2** and a parallel resonator P**1**. The metal layer **14** functions as an input pad In, an output pad Out, and ground pads Gnd. The input pad In, the output pad Out, and the ground pads Gnd are electrically connected to the input terminal, the output terminal, and the ground terminal provided on the lower surface of the substrate **10** via the via wirings **16**. The metal pillar **36** is provided on the input pad In. The series resonators S**1** and S**2** are connected in series between the input pad In and the output pad Out, and the parallel resonator P**1** is connected in parallel between the input pad In and the output pad Out.

[0033] As illustrated in FIG. **3**B, the annular metal layer **38** is provided on the peripheral edge of the substrate **20**. An inductor is formed as the element **21** by the metal layer **24**. One end of the element **21** is electrically connected to the input pad In of FIG. **3**A via the metal pillar **36**. The other end of the element **21** is connected to the annular metal layer **38** by the metal layer **24**, and is connected to the ground terminal via the via wiring **16** of FIG. **3**A. Thereby, the inductor is connected between the input terminal Tin and the ground terminal Tgnd.

[0034] FIGS. **4**A to **4**D and **5**A to **5**B are cross-sectional views illustrating a method of manufacturing the acoustic wave device according to the first embodiment. As illustrated in FIG. **4**A, the piezoelectric substrate **10***a* at the peripheral edge of the substrate **10** to which the piezoelectric substrate **10***a* is bonded to an upper surface of the support substrate **10***b* is removed. Holes are formed in the substrate **10** and via wirings **16** are formed in the holes. The via wirings **16** do not penetrate the substrate **10**. The acoustic wave element **12** and the metal layers **14** and **15** are formed on the substrate **10**.

[0035] As illustrated in FIG. **4**B, the metal layers **30** are formed on the metal layers **14** and **15**. A plating method is used to form each metal layer **30**. A side surface of an opening of the photoresist, which serves as a mask for plating, are inverse tapered (the width at the top of the opening is smaller than the width at the bottom of the opening), so that the side surface of the metal layer **30** are tapered (the width at the top of the metal layer **30** is smaller than the width at the bottom of the metal layer **30**). Distances from the support substrate **10***b* to the upper surface of the metal layers **30** differ between the metal layer **30** provided on the piezoelectric substrate **10***a* and the metal layer **30** provided on the support substrate lob from which the piezoelectric substrate **10***a* is removed.

[0036] As illustrated in FIG. **4**C, the upper surfaces of the metal layers **30** are ground. Thereby, the distances from the support substrate **10***b* to the upper surfaces of the metal layers **30** are the same as each other. The upper surface of each metal layer **30** is flattened by using, for example, a CMP (Chemical Mechanical Polishing) method. As a result, an arithmetic mean roughness of the upper surface of the metal layer **30** is set to, for example, 1 nm or less.

[0037] As illustrated in FIG. **4**D, a metal layer **33** is formed so as to cover the metal layer **30**. For example, a sputtering method and a lift-off method are used to form the metal layer **33**. The side surface of the metal layer **30** does not have to be tapered, but if it is tapered, the covering property of the metal layer **33** is improved. Further, depending on the film forming conditions of the metal layer **33**, the thickness of the metal layer **33** on the metal layer **14** (T**4***b* and T**5***b* in FIG. **1**B) can be made thicker than the thickness of the metal layer **33** on the side surface of the metal layer **30** (T**4***a* and T**5***a* in FIG. **1**B).

[0038] As illustrated in FIG. **5**A, the substrate **10** of FIG. **4**D is turned upside down and the substrate **10** is placed on the substrate **20**. The upper surface of the metal layer **33** (that is, the upper surface of the metal layer **32**) and the lower surface of the metal layer **24***c* are irradiated with a beam of an inert gas such as argon, so that the upper surface of the metal layer **33** and the lower surface of the metal layer **24***c* are activated. At this time, the arithmetic mean roughness Ra of the upper surface of the metal layer **33** and the lower surface of the metal layer **24***c* is 1 nm or less. Then, as illustrated in FIG. **5**B, the metal layer **33** and the metal layer **24***c* on the metal layer **30** (see FIG. **1**B) are bonded by pressurizing. Such a surface activation method is performed at room temperature (for example, 0° C. or more and 100° C. or less). The use of the same main components in the metal layer **24***c* and an upper part of metal layer **33** facilitate the bonding of the metal layers **33** and **24***c* at room temperature by the surface activation method. Then, a lower surface of the support substrate **10***b* is polished until the via wiring **16** is exposed. The terminal **18** is formed on the lower surface of the support substrate **10***b*. As described above, the acoustic wave device according to the first embodiment is manufactured.

First Comparative Example

[0039] FIG. **6** is an enlarged view illustrating the vicinity of a metal pillar in a first comparative example. In the first comparative example, a metal pillar **36***b* and the metal layer **24** are bonded by a solder **37**. The metal layer **24** includes a metal layer **24***d* between the metal layer **24***a* and the solder **37**. The metal layer **24***d* is a layer having good solder wettability, for example, a nickel layer. The piezoelectric substrate **10***a* is charged by a temperature and a stress. Thereby, an electric field is applied to the metal pillar **36***b*. When moisture is supplied while the electric field is applied, ion migration occurs in which the metal ions in the metal pillar **36** migrate. Copper and silver are elements that are likely to generate the ion migration. Similarly, tin in the solder **37** is an element that is likely to generate the ion migration. When copper or silver ions migrate to the acous-

tic wave element **12** as illustrated by an arrow **52***a* and tin ions migrate to the acoustic wave element **12** as illustrated by an arrow **52***b*, the acoustic wave element **12** deteriorates. For example, a region between the electrode fingers of the acoustic wave element **12** is short-circuited. A change in temperature or stress during the manufacturing or the use of the acoustic wave device causes the ion migration of copper or silver, which degrades the acoustic wave element **12**.

[0040] According to the first embodiment, at least a part of the upper surface (first surface) of the substrate **10** (first substrate) is the piezoelectric substrate **10***a* (piezoelectric layer), and the acoustic wave element **12** is provided on the piezoelectric substrate **10***a*, as illustrated in FIG. **1**B. The substrate **20** (second substrate) is provided via the acoustic wave element **12** and the space **28**. The metal layer **14** (first metal layer) is provided on the upper surface (first surface on substrate **20** side) of the substrate **10** and is electrically connected to the acoustic wave element **12**. The metal layer **24** (second metal layer) is provided on the lower surface of the substrate **20** (second surface on substrate **10** side). The metal layer **30** (third metal layer) connects the metal layer **14** to the metal layer **24**.

[0041] In such a structure, the metal layer **30** thicker than the metal layers **14** and **24** contains copper or silver as a main component in order to reduce the resistance of the metal pillar **36**. When the metal layer **14** is conductive to the acoustic wave element **12** provided on the piezoelectric substrate **10***a* which is easily charged, an electric field is applied to the metal layer **30**. This may cause copper or silver in the metal layer **30** to migrate to the acoustic wave element **12** due to the ion migration as in the first comparative example, resulting in degradation of the acoustic wave element **12**.

[0042] The metal layer **33** (first conductive layer) that is thinner than the metal layer **30** and contains a component other than copper, silver, and tin as a main component (that is, does not contain copper, silver, and tin as the main component) is provided so as to cover the side surface of the metal layer **30**, and the upper surface (third surface) of the metal layer **30** in the region **50** surrounding the bonding region **51** to which the metal layer **30** is bonded to the metal layer **14**. Thereby, the metal layer **33** serves as a barrier for the ion migration of copper or silver as illustrated by the arrow **52***a* in FIG. **6**. Therefore, the ion migration of copper or silver ions to the acoustic wave element **12** can be suppressed. The metal layer **30** preferably contains copper as the main component. Thereby, the metal layer **30** can be easily formed by the plating method as compared with a case where the metal layer **30** contains silver as the main component.

[0043] The thickness T4*b*+T5*b* of the metal layer **33** covering the region **50** is thicker than the thickness T4*a*+T5*a* of the metal layer **33** covering the side surface of the metal layer **30**. Thereby, the metal layer **33** in the region **50** further suppresses the ion migration of copper or silver from the metal layer **30** to the acoustic wave element **12**.

[0044] The metal layer **33** further covers the upper surface (surface on the substrate **20** side) of the metal layer **30** and is directly bonded to the metal layer **24**. Since the metal layer **33** does not contain tin as the main component, it is not necessary to use the solder **37** as in the first comparative example. This can prevent the ion migration of tin to the acoustic wave element **12** as illustrated by the arrow **52***b*.

[0045] The metal layer **34** (second conductive layer) is bonded to the metal layer **24**, and the metal layer **32** (third conductive layer) is provided between the metal layers **34** and **30**. Thereby, the metal layer **34** can be made of a material that can easily be bonded to the metal layer **24**, and the metal layer **32** can be made of a material that can easily serve as a barrier for copper or silver.

[0046] The metal layer **24***c* in the metal layer **24** to be bonded to the metal layer **34** has the same main component as the main component of the metal layer **34**. This can suppress the formation of an intermetallic compound between the metal layers **24***c* and **34**. Therefore, the bonding quality between the metal layers **24***c* and **34** can be improved.

[0047] When the temperature of the piezoelectric substrate **10***a* becomes high, it becomes easy to be charged due to stress or the like. Further, when the temperature becomes high, the moisture is released into the space **28** from the metal layer **30** and the like formed by the plating method. The moisture in the space **28** facilitates the ion migration of copper or silver in the metal layer **30**. When the metal layers **34** and **24** are bonded at the high temperature, the ion migration of copper or silver is likely to occur as described above. Therefore, the metal layers **24** and **34** are bonded at room temperature by using the surface activation method. This can suppress the ion migration.

[0048] The metal layer **34** contains gold or aluminum as a main component. This facilitates direct bonding of the metal layers **24** and **30**. The metal layer **34** preferably contains gold as the main component. This further facilitates direct bonding of the metal layers **24** and **30**. Also, gold and aluminum are less likely to generate the ion migration than copper or silver.

[0049] The metal layer **32** contains at least one element of titanium, chromium, tantalum, nickel, tungsten and ruthenium, and a nitride of these elements as the main component. This allows these elements or the nitride to function as a barrier for the ion migration of copper or silver. Therefore, the ion migration can be further suppressed.

[0050] The metal pillar **36** including the metal layer **30** connects the substrate **10** to the substrate **20**. In this way, the metal pillar **36** preferably contains copper or silver as a main component in order to electrically connect the substrate **10** to the substrate **20**. Therefore, it is preferable to provide the metal layer **33** that suppresses the ion migration. It should be noted that copper or silver may migrate from the metal layer **30** of the annular metal layer **38** to the acoustic wave element **12**. Therefore, it is preferable to provide the metal layer **33** in the annular metal layer **38**.

[0051] The substrate **10** includes the support substrate **10***b* and the piezoelectric substrate **10***a* provided on the support substrate **10***b*. A thermal expansion coefficient of the support substrate **10***b* is made smaller than a thermal expansion coefficient of the piezoelectric substrate **10***a* in a propagation direction of the acoustic wave. Thereby, the temperature change of the acoustic wave element **12** can be suppressed. However, since a thermal stress is applied to the piezoelectric substrate **10***a*, the piezoelectric substrate **10***a* is likely to be charged. Therefore, the electric field in the metal layer **30** becomes large, and the ion migration is likely to occur. Therefore, it is preferable to provide the metal layer **33** that suppresses the ion migration.

[0052] When the metal layer **30** is provided on the piezoelectric substrate **10***a*, the piezoelectric substrate **10***a* is

charged by the stress applied from the metal layer **30** to the piezoelectric substrate **10***a*, and the electric field applied to the metal layer **30** is likely to increase. This facilitates the ion migration of copper or silver in the metal layer **30**. Therefore, it is preferable to provide the metal layer **33**.

[0053] The substrate **20** is not provided with an element and may be simply a lid. However, when the substrate **20** is provided with a passive element or the like, the metal layer **30** is preferably made of copper or silver as a main component in order to electrically connect the element **21** to the acoustic wave element **12**. Therefore, it is preferable to provide the metal layer **33** that suppresses the ion migration.

[0054] No solder layer containing tin is provided between the substrates **10** and **20**. This can suppress the ion migration of tin, as illustrated by the arrow **52***b* in FIG. **6**.

[0055] The main component of a certain metal layer as a certain element or compound includes the unintentional or intentional inclusion of impurities in the certain metal layer. For example, the concentration of the certain element or compound in the metal layer is 50 atomic % or more, 80 atomic % or more, or 90 atomic % or more.

First Modification of First Embodiment

[0056] FIG. **7**A is a cross-sectional view illustrating an acoustic wave device according to a first modification of the first embodiment. FIG. **7**B is an enlarged view illustrating the vicinity of the metal pillar in FIG. **7**A. As illustrated in FIGS. **7**A and **7**B, the piezoelectric substrate **10***a* under the metal pillar **36** is removed. The metal pillar **36** is provided on the support substrate **10***b* from which the piezoelectric substrate **10***a* is removed. Even when the metal pillar **36** is not provided on the piezoelectric substrate **10***a* as in the first modification of the first embodiment, if the acoustic wave element **12** and the metal layer **30** are electrically connected via the metal layer **14**, an electric field is applied to the metal layer **30** due to electrification of the piezoelectric substrate **10***a*. Thus, the ion migration of copper or silver in the metal layer **30** may occur. Therefore, it is preferable to provide the metal layer **33**. Other configurations are the same as those of the first embodiment, and the description thereof will be omitted.

Second Modification of First Embodiment

[0057] FIG. **8**A is a cross-sectional view illustrating an acoustic wave device according to a second modification of the first embodiment. As illustrated in FIG. **8**A, the substrate **10** is a piezoelectric substrate, and the metal pillar **36** and the annular metal layer **38** are provided on the piezoelectric substrate. Other configurations are the same as those of the first embodiment, and the description thereof will be omitted.

Third Modification of First Embodiment

[0058] FIG. **8**B is a cross-sectional view illustrating an acoustic wave device according to a third modification of the first embodiment. As illustrated in FIG. **8**B, the substrate **20** includes a support substrate **20***b* and a piezoelectric substrate **20***a* provided under the support substrate **20***b*. An acoustic wave element **22** and the metal layer **24** are provided on a lower surface of the piezoelectric substrate **20***a*. The piezoelectric substrate **20***a*, the support substrate **20***b*, the acoustic wave element **22**, and the metal layer **24** have the same configuration as the piezoelectric substrate **10***a*, the support substrate **10***b*, the acoustic wave element **12**, and the metal layer **14**, and the description thereof will be omitted. A metal pillar **36***a* and an annular metal layer **38***a* are provided under the metal layer **24**. Each of the metal pillar **36***a* and the annular metal layer **38***a* includes metal layers **30***a* and **33***a*. The metal layers **30***a* and **33***a* have the same configuration as the metal layers **30** and **33**, and the description thereof will be omitted. The metal layer **33** on an upper surface of the metal pillar **36** and the metal layer **33***a* on a lower surface of the metal pillar **36***a* are directly bonded to each other, and the metal layer **33** on an upper surface of the annular metal layer **38** and the metal layer **33***a* on a lower surface of the annular metal layer **38***a* are directly bonded to each other. Other configurations are the same as those of the first embodiment, and the description thereof will be omitted.

Fourth Modification of First Embodiment

[0059] FIG. **9** is a cross-sectional view illustrating an acoustic wave device according to a fourth modification of the first embodiment. As illustrated in FIG. **9**, a piezoelectric thin film resonator is provided as the acoustic wave element **22** under the substrate **20**.

[0060] FIG. **10** is a cross-sectional view illustrating an acoustic wave element according to the fourth modification of the first embodiment. As illustrated in FIG. **10**, in the acoustic wave element **22** which is the piezoelectric thin film resonator, a piezoelectric film **46** is provided on the substrate **20**. A lower electrode **44** and an upper electrode **48** are provided so as to sandwich the piezoelectric film **46**. A gap **45** is formed between the lower electrode **44** and the substrate **10**. A region where the lower electrode **44** and the upper electrode **48** that sandwich at least a part of the piezoelectric film **46** and face each other is a resonance region **47**. In the resonance region **47**, the lower electrode **44** and the upper electrode **48** excite acoustic waves in a thickness longitudinal vibration mode in the piezoelectric film **46**. The lower electrode **44** and the upper electrode **48** are metal films such as a ruthenium film. The piezoelectric film **46** is, for example, an aluminum nitride film. An acoustic reflection film that reflects the acoustic waves may be provided instead of the gap **45**. Other configurations are the same as those of the third modification of the first embodiment, and the description thereof will be omitted.

[0061] As in the third and the fourth modifications of the first embodiment, at least a part of the lower surface (second surface) of the substrate **20** is the piezoelectric substrate **20***a* (another piezoelectric layer), and the acoustic wave element **22** (another acoustic wave element) is provided on the piezoelectric substrate **20***a*. The metal layer **30***a* (fourth metal layer) connects the metal layer **24** to the metal layer **30**, is thicker than the metal layers **14** and **24**, and contains copper or silver as a main component. The metal layer **33***a* (fourth conductive layer) covers the side surface of the metal layer **30***a* and the lower surface (fourth surface) of the metal layer **24** in another region surrounding a region where the metal layer **30***a* bonds the metal layer **24**. The metal layer **33***a* is thinner than the metal layer **24** and contains components other than copper, silver and tin as main components. This can suppress the ion migration of copper or silver in the metal layer **30***a* to the acoustic wave element **22**. Since the annular metal layers **38** and **38***a* are bonded to each other, the strength is easily weakened. Therefore, the widths of the

annular metal layers **38** and **38***a* are preferably larger than the width of the annular metal layer **38** of the first embodiment.

Fifth Modification of First Embodiment

[0062] FIG. **11** is a cross-sectional view illustrating an acoustic wave device according to a fifth modification of the first embodiment. As illustrated in FIG. **11**, the piezoelectric substrate **20***a* in the substrate **20** is provided on the upper surface of the support substrate **20***b*. Metal layers **27***a* and **27***b* are provided on the lower surface of the substrate **20**. The metal pillar **36** and the annular metal layer **38** are bonded to the metal layers **27***a* and **27***b*, respectively. The metal layer **27***a* functions as a shield. A lid **54** is provided above the substrate **20**. A metal layer **55** is provided on the lower surface of the lid **54**. A via wiring **56** that penetrates the lid **54** is provided. A metal layer **58** is provided on the lid **54**. The via wiring **56** connects the metal layer **55** to the metal layer **58**. The metal pillar **36***a* and the annular metal layer **38***a* are bonded to the metal layer **55**. he lid **54** and the annular metal layer **38***a* seal the acoustic wave element **22** in a space **28***a*. Other configurations are the same as those of the third modification of the first embodiment, and the description thereof will be omitted. An element may be provided on the substrate **20** as in the fifth modification of the first embodiment.

[0063] In the first embodiment and its modifications, an example of the inductor and the acoustic wave element **22** (the piezoelectric thin film resonator or acoustic surface wave resonator) as the element **21** is described. However, the element **21** may be a passive element such as an inductor or a capacitor, an active element including a transistor, or a MEMS (Micro Electro Mechanical Systems) element.

Second Embodiment

[0064] FIG. **12**A is a circuit diagram illustrating a filter according to a second embodiment. As illustrated in FIG. **12**A, one or a plurality of series resonators S**1** to S**4** are connected in series between an input terminal Tin and an output terminal Tout. One or more parallel resonators P**1** to P**4** are connected in parallel between the input terminal Tin and the output terminal Tout. The filter of the second embodiment may be formed by the acoustic wave element **12**. The number of series resonators and the number of parallel resonators can be set as appropriate. An example of a ladder type filter is described as a filter, but the filter may be a multiple mode type filter.

[0065] FIG. **12**B is a circuit diagram illustrating a duplexer according to a first modification of the second embodiment. As illustrated in FIG. **12**B, a transmission filter **60** is connected between a common terminal Ant and a transmission terminal Tx. A reception filter **62** is connected between the common terminal Ant and a reception terminal Rx. The transmission filter **60** passes, to the common terminal Ant, signals in a transmission band among the high frequency signals input from the transmission terminal Tx as transmission signals, and suppresses signals having other frequencies outside the transmission band. The reception filter **62** passes, to the reception terminal Rx, signals in a reception band among the high frequency signals input from the common terminal Ant as reception signals, and suppresses signals having other frequencies outside the reception band. At least one of the transmission filter **60** and the reception filter **62** can be the filter of the second embodiment.

[0066] Although an example of the duplexer is described as the multiplexer, the multiplexer may be a triplexer or a quadplexer.

[0067] Although the embodiments of the present invention have been described in detail, it is to be understood that the various change, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. An acoustic wave device comprising:

a first substrate having at least a part of a first surface that is a piezoelectric layer;

an acoustic wave element provided on the first surface of the piezoelectric layer;

a second substrate provided apart from the first substrate via the acoustic wave element and a gap;

a first metal layer provided on the first surface and conductively connected to the acoustic wave element;

a second metal layer provided on a second surface of the second substrate on a first substrate side;

a third metal layer that connects the first metal layer to the second metal layer, is thicker than the first metal layer and the second metal layer, and contains copper or silver as a main component; and

a first conductive layer that covers a side surface of the third metal layer, and a third surface of the first metal layer on a second substrate side in a region surrounding another region where the third metal layer is bonded to the first metal layer, is thinner than the third metal layer, and contains a component other than copper, silver, and tin as a main component.

2. The acoustic wave device as claimed in claim **1**, wherein

a first portion of the first conductive layer covering the third surface is thicker than a second portion of the first conductive layer covering the side surface of the third metal layer.

3. The acoustic wave device as claimed in claim **1**, wherein

the first conductive layer further covers a surface of the third metal layer on the second substrate side and is directly bonded to the second metal layer.

4. The acoustic wave device as claimed in claim **3**, wherein

the first conductive layer includes a second conductive layer directly bonded to the second metal layer, and a third conductive layer provided between the second conductive layer and the third metal layer.

5. The acoustic wave device as claimed in claim **4**, wherein

a region in the second metal layer to be bonded to the second conductive layer has the same main component as a main component of the second conductive layer.

6. The acoustic wave device as claimed in claim **4**, wherein

the second conductive layer contains gold or aluminum as the main component.

7. The acoustic wave device as claimed in claim **4**, wherein

the third conductive layer contains at least one element of titanium, chromium, tantalum, nickel, tungsten and ruthenium, and a nitride of the at least one element as the main component.

8. The acoustic wave device as claimed in claim **1**, further comprising

a metal pillar containing the third metal layer.

9. The acoustic wave device as claimed in claim **1**, wherein

the first substrate includes a support substrate, and the piezoelectric layer provided on the support substrate.

10. The acoustic wave device as claimed in claim **1**, further comprising

an element provided on a surface of the second substrate on the first substrate side.

11. The acoustic wave device as claimed in claim **1**, wherein

at least a part of the second surface of the second substrate is another piezoelectric layer, and

the acoustic wave device further includes:

another acoustic wave element provided on the another piezoelectric layer;

a fourth metal layer that connects the second metal layer to the third metal layer, is thicker than the first metal layer and the second metal layer, and contains copper or silver as a main component; and

a fourth conductive layer that covers a side surface of the fourth metal layer, and a fourth surface of the second metal layer on the first substrate side in a region surrounding another region where the fourth metal layer is bonded to the second metal layer, is thinner than the fourth metal layer, and contains a component other than copper, silver, and tin as a main component.

12. A filter comprising the acoustic wave device as claimed in claim **10**.

13. A multiplexer comprising the filter as claimed in claim **12**.

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